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Vegetation diversity and air pollution mitigation in urban green areas

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ABSTRACT
Background: Fine particulate matter ($PM_{2.5}$) pollution is a major environmental and public health concern in Jakarta. Urban green open spaces may contribute to air pollution mitigation through vegetation characteristics. This study aimed to examine the association between vegetation diversity and annual mean ambient $PM_{2.5}$ concentrations in two urban green spaces in Jakarta. **Methods:** A quantitative and spatial analysis was conducted using vegetation plot data, Sentinel-2A imagery, and secondary air-quality data. Vegetation structure and diversity were analyzed using the Importance Value Index and Shannon–Wiener diversity index. Spatial vegetation distribution was analyzed using QGIS 3.34.4 and Sentinel-2A. **Findings:** Tebet Eco Park had a higher tree-species diversity index (H' = 2.32) than integrated child-friendly public space/*ruang publik terpadu ramah anak (RPTRA)* Kelapa Nias III (H' = 1.52). The corresponding annual mean ambient $PM_{2.5}$ concentrations were 28 μg/m^3 for the area associated with Tebet Eco Park and 31.9 μg/m^3 for the area associated with RPTRA Kelapa Nias III. The lower $PM_{2.5}$ value observed in the Tebet Eco Park area coincided with greater tree diversity and denser vegetation cover. However, because the $PM_{2.5}$ data were obtained from secondary regional monitoring and the study did not directly measure traffic intensity, meteorological conditions, local emission sources, or pedestrian-level exposure, the findings should be interpreted as an observed association rather than evidence of a direct causal effect of vegetation. **Conclusion:** Tree-species diversity and vegetation structure may support the air-quality and public health functions of urban green spaces. Urban green-space management should prioritize species diversification, multilayered vegetation, shrubs and hedges near pedestrian areas, and the integration of vegetation planning with site-level air-quality, traffic, and meteorological monitoring. **Novelty/Originality of this article:** This study provides a public health-oriented comparison of two urban green spaces by integrating field-based vegetation diversity and structure, satellite-derived vegetation density, and annual $PM_{2.5}$ data, thereby offering context-specific evidence for vegetation-quality-based urban greening in Jakarta.

KEYWORDS: air pollution; green open space; PM2.5; urban biodiversity.

1. Introduction

In line with the growth of development, transportation, industry, and urbanization, air quality can also change due to air pollution. Air pollution is a process in which the composition of air changes due to the presence of pollutants or contaminants (World Health Organization [WHO], 2024). According to the 6th World Air Quality Report, in 2023, Bangladesh, Pakistan, India, Tajikistan, and Burkina Faso were the five most polluted countries in the world. According to a report by IQAir (2026) on Southeast Asia, Indonesia remains in first place as the most polluted country, and Jakarta ranks seventh among the

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most polluted cities in the world. The total particulate matter (PM)emission load in Jakarta currently stands at approximately 4.6 kilotons, with these emissions primarily originating from road vehicles and the industrial combustion sector (Cholianawati et al., 2024). According to data from the IQAir air quality monitoring website, Jakarta's Air Quality Index (AQI) stood at 170 in April 2026—classified as "unhealthy" air—with a $PM_{2.5}$ concentration of 82 µg/m^3.

Air pollution can cause several health problems in humans. These health problems include lung cancer and diseases related to the cardiovascular and respiratory systems (Chen et al., 2024). Compared to PM_{10}, $PM_{2.5}$ remains suspended in the atmosphere for longer periods and can penetrate deep into the bronchi and alveoli, causing serious damage to the human body (Schraufnagel et al., 2019). The public health consequences of ambient PM have been well documented by epidemiological, toxicological, and clinical studies for more than three decades. The global disease burden caused by PM is at an all-time high and is estimated to exceed 5 million deaths per year (Greenwald et al., 2024). Fine $PM_{2.5}$ should be framed not only as an environmental pollutant but also as a major public health risk factor. Evidence from cohort studies in the Asia-Pacific region shows that long-term $PM_{2.5}$ exposure is consistently associated with increased all-cause and cardiovascular mortality, as well as higher incidence of cardiovascular disease, chronic obstructive pulmonary disease, type 2 diabetes mellitus, and kidney diseases (Yang et al., 2022).

Air pollution has become a serious issue that cannot be addressed solely through the control of emission sources. Among the available mitigation strategies, urban vegetation has attracted increasing attention because it can improve air quality while providing multiple ecological benefits. Green spaces offer a potential solution and represent an essential component of urban environments, as they are the only ecosystems in urban areas that can function as natural air purifiers (Veerkamp et al., 2021). Urban reen pen paces (UGOS) are outdoor areas that promote healthy living conditions for urban residents and effectively regulate the urban ecological environment through rational planning and design (Zhang et al., 2024). Although many studies have demonstrated the air purification benefits of urban green spaces, their effectiveness varies depending on vegetation characteristics and surrounding environmental conditions. Studies examining the relationship between green spaces and airborne particulate concentrations have been conducted at multiple scales, including site, plant community, and individual plant levels (Yin et al., 2022). At the site scale, urban air pollution is influenced not only by traffic and industrial emissions but also by land use types, meteorological conditions, and population density (Zhang et al., 2024). Nature-based Solutions (NBS) are an important approach to addressing air pollution, but they can also serve as a solution for enhancing biodiversity. Solutions of this kind can also serve as efforts to conserve or enhance biodiversity, which is also one of the Sustainable Development Goals targets (Target 15: Life on Land).

Plant diversity plays an important role in air pollution mitigation because different species possess distinct canopy structures and leaf surface characteristics that influence particulate capture efficiency (Wu et al., 2021). Wu et al. (2021). Greening initiatives in urban areas, which serve as solutions to mitigate PM pollution in urban settings, encompass various strategies such as roadside trees, hedges, parks, green roofs, and green walls (Chang et al., 2024). Based on a study conducted by Biocca et al. (2024), it has been shown that plants offer an effective method for air purification, particularly for particulate pollution from decentralized sources, thanks to their widespread distribution. have shown that plants offer an effective method of air purification, particularly for non-point-source particulate pollution, due to their widespread distribution. For example, greening interventions in North Macedonia showed a substantial reduction of 25% in $PM_{2.5}$ and 37% in PM_{10} in areas undergoing greening (Srbinovska et al., 2021). These findings suggest that vegetation diversity should be considered an important component of urban air quality management.

The extent of PM reduction by vegetation can be influenced by factors such as leaf area index (LAI), leaf area density (LAD), vegetation height and density, etc. For example, vegetation with a large surface area and complex structure is highly efficient at capturingPM. Additionally, vegetation influences pollutant dispersion through its impact on local wind patterns. Trees and other plants can create turbulence that helps disperse pollutants, thereby diluting their concentration and spreading them over a wider area. Vegetative barriers, such as hedges and green walls, act as windbreaks, reducing wind speed and promoting particle deposition, while simultaneously blocking air pollution from reaching people, such as trees between traffic lanes and pedestrians. Pedestrians in urban areas are highly vulnerable to the harmful effects of air pollution because they spend a significant amount of time walking near roadways where pollutant concentrations can be high (Daghistani & Abduljabbar, 2024). Weather conditions, particularly wind speed and direction, also influence pollutant concentrations by affecting particle dispersion and accumulation. Pedestrian exposure is typically higher in windy areas near emission sources (Polednik & Piotrowicz, 2020). Traffic volume and speed, as well as the placement and height of buildings, are other factors that influence pollutant concentrations in the roadside environment (Daghistani & Abduljabbar, 2024). Therefore, the effectiveness of vegetation in reducing PM depends not only on plant characteristics but also on surrounding meteorological conditions and the urban environment.According to a study conducted by Kacprzak et al. (2024), urban forests have been shown to be effective in reducing air pollution by lowering the concentrations of various pollutants, such as $PM_{2.5}$, PM_{10}, NO_2, SO_2, and O_3.However, the removal of air pollutants by urban vegetation is influenced by various factors, including ambient pollutant concentrations, meteorological conditions, vegetation characteristics, canopy structure, and the extent of green-space coverage (Diener & Mudu, 2021; Gong et al., 2023; Nowak et al., 2006). Increasing vegetation cover has therefore been widely recommended as a complementary strategy for improving urban air quality alongside conventional emission-control measures, rather than as a substitute for pollution control at the source(Chaudhuri & Kumar, 2022). Policies for expanding green open spaces should be implemented through sound planning that considers local geographical conditions and native species. Currently, Pemerintah Provinsi DKI Jakarta (2025) reports that the area of green open spaces in the capital region totals 33.34 million square meters, representing only 5.6% of the province's total area, with 24.87% in South Jakarta and 20.93% in North Jakarta.

According to the Indonesian Law No. 26 of 2007 concerning Spatial Planning, the area of green open space in this region remains below the ideal urban green open space standard of 30% of the city's total area. Srbinovska et al. (2021) indicates that the placement of green infrastructure in urban environments must be carefully planned to maximize its impact on air quality. An important factor to consider when selecting plant species is their ability to filter PMfrom the air. PM removal occurs primarily through particle interception and deposition on leaf surfaces, particularly those with hairy, rough, or waxy textures.

In addition to vegetation factors, the characteristics of green open spaces influence the effectiveness of air pollution reduction. Larger green open spaces with more complex vegetation structures generally have a greater ability to increase air turbulence and prolong particle residence time, thereby increasing the likelihood of $PM_{2.5}$ deposition. Conversely, green open spaces with limited area and homogeneous vegetation have limitations in performing these ecological functions. Therefore, the quality of green open spaces is determined not only by their area but also by the vegetation composition and structure (Jeong et al., 2023; Sun et al., 2024; Wang et al., 2026).

The role of greenness as a potential protective factor against air pollution-related health outcomes is further supported by recent epidemiological evidence. In Wuhan, higher residential greenness was reported to alleviate $PM_{2.5}$-associated hospitalization risks for cardiovascular diseases (Yang et al., 2023). Similarly, a cohort study among older adults in Hong Kong found that higher residential greenness reduced susceptibility to respiratory mortality associated with short-term exposure to air pollution (Sun et al., 2020). A prospective cohort study among individuals with type 2 diabetes in Shanghai also found that higher NDVI was associated with reduced all-cause and cause-specific mortality, with part of the protective association mediated by lower $PM_{2.5}$ and NO_2 exposure (Wu et al., 2024). Collectively, these findings suggest that increasing urban greenness may reduce adverse health outcomes by lowering long-term exposure to air pollutants.However, public health risk reduction cannot be inferred from the presence of vegetation alone. PM2.5 exposure is influenced by population mobility, traffic density, industrial activity, land use, meteorological conditions, and the spatial distribution of people in polluted areas. Health risk assessment studies using population distribution and $PM_{2.5}$ monitoring data have shown that exposure risk varies spatially and depends on where people live, move, and conduct daily activities (He et al., 2020).

Therefore, urban green space research should avoid assuming a direct causal relationship between vegetation diversity and lower $PM_{2.5}$ concentration without considering the surrounding urban emission sources and exposure conditions. Based on this public health-oriented framework, this study hypothesizes that urban green open spaces with higher vegetation diversity are associated with lower ambient $PM_{2.5}$ concentrations, which may reduce public health risk by decreasing the potential exposure to fine PM. Accordingly, this study aims to examine the association between vegetation diversity and $PM_{2.5}$ concentrations in selected urban green open spaces in Jakarta, and to discuss their implications of these findings for urban green space planning and public health-oriented environmental management.

2. Methods

2.1 Data collection methods

Data collection was conducted by recording vegetation composition, including the identification of all plant species present at the study sites using their local and scientific names. Vegetation surveys were conducted using the plot method, and only trees with a diameter at breast height (DBH) greater than 20 cm were included to represent mature canopy-forming vegetation. For each sampled tree, DBH, total height, and canopy width were measured and recorded on vegetation survey sheets. Each measured tree was marked to prevent duplicate recording. PM2.5 concentration data were obtained from the *2025 Air Quality Report* published by the DKI Jakarta Provincial Environmental Agency.

2.2 Data analysis methods

This study was conducted at two GOSsites located in South Jakarta and North Jakarta: Tebet Eco Park and RPTRA Kelapa Nias III and this study analyzed the extent of green open spaces (GOS) using spatial analysis methods with the assistance of QGIS 3.34.4 software and Sentinel-2A imagery acquired in May 2025 to obtain an overview of GOS distribution in accordance with policies, as viewed through the lens of population density in South Jakarta and North Jakarta. The Sentinel-2A Level-2A image was selected based on low cloud-cover availability over the study area and provides atmospherically corrected surface reflectance data. Band 4 (Red) and Band 8 (Near Infrared/NIR), both with 10 m spatial resolution, were used to calculate the Normalized Difference Vegetation Index (NDVI).

Table 1. The diversity index category (H’)

Index	Category
$H'<1$	Low
$1 \le H' \le 3$	Medium
$H'>3$	High

(Odum, 1971)

The boundaries of Tebet Eco Park and RPTRA Kelapa Nias III were digitized as vector polygons and clipped to the Sentinel-2A raster image. The NDVI output was then classified into vegetation density classes to compare the vegetation cover between the two study sites. Sentinel-2A is a European optical imaging satellite launched in 2015. This satellite can be used to conduct terrestrial observations to support services such as forest monitoring, land cover change detection, and natural disaster management (Fardilla et al., 2023). The analysis of vegetation composition within the GOS involved classifying identified trees based on species, diameter, height, and crown width. Measurements of the vegetation species diversity index at the study site, categorized by index, are presented in Table 1. Vegetation structure and composition were evaluated by calculating the Important Value Index (IVI), while species diversity was assessed using the Shannon–Wiener diversity index (H').. The IVI is calculated using the following formula pi = $\frac{Ni}{N}$, Ni is number of individuals of species, and N is total number of individuals of all species

$$\text{Density (De)} = \frac{\text{Number of individuals of each species}}{\text{Total area of all plots}}\ (\text{ind/ha}) \quad \text{(Eq. 1)}$$

$$\text{Relative Density (RDe)} = \frac{\text{Density of a species}}{\text{Density of all species}} \times 100\% \quad \text{(Eq. 2)}$$

$$\text{Frequency (F)} = \frac{\text{Number of plots where a species was found}}{\text{Total number of plots}} \quad \text{(Eq. 3)}$$

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} \times 100\% \quad \text{(Eq. 4)}$$

$$\text{Dominance (Do)} = \frac{\text{Total basal area}}{\text{Plot area}}\ (\text{m}^2/\text{ha}) \quad \text{(Eq. 5)}$$

$$\text{Relative Dominance (RDo)} = \frac{\text{Dominance of a species}}{\text{Dominance of all species}} \times 100\% \quad \text{(Eq. 6)}$$

$$\text{IVI for trees} = \text{RDe} + \text{RF} \quad \text{(Eq. 7)}$$

$$\text{Diversity Index (H')} = -\sum \{\text{pi ln pi}\} \quad \text{(Eq. 8)}$$

The base area is calculated using the following equation with π is 3.14 and D for diameter of the tree trunk at chest height (m). The data collection and analysis techniques regarding the ability of existing vegetation to reduce $PM_{2.5}$ focus on using data obtained from the Environmental Agency (DLH). This air quality data collection involves secondary data derived from air quality monitoring conducted by the DLH, which has recorded $PM_{2.5}$ measurement results as well as meteorological conditions at various points in South Jakarta and North Jakarta.

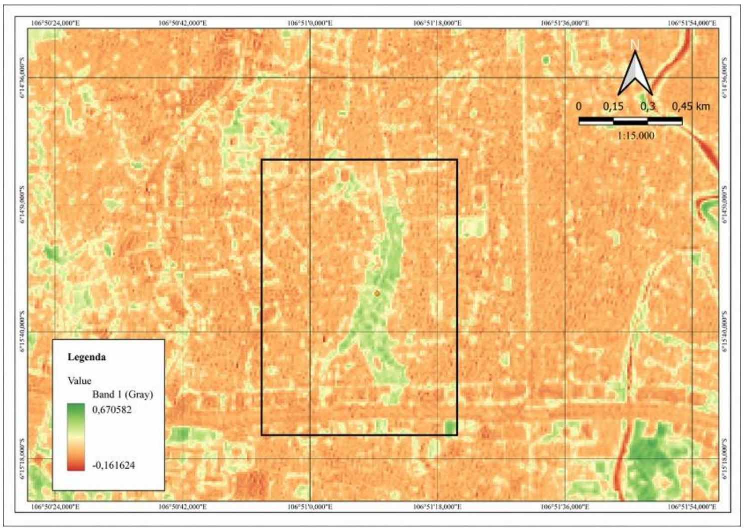
$$Base\ Area\ (BA) = \frac{1}{4}\,\pi\, D2 \quad \text{(Eq. 9)}$$

The DLH routinely collects data using air quality monitoring devices installed at various strategic locations deemed representative of the city’s environmental conditions. PM2.5 concentrations were monitored continuously in real time throughout the year and recorded at hourly intervals. The hourly measurements were subsequently aggregated into daily average concentrations for analysis., providing an overview of the fluctuations in $PM_{2.5}$ levels over time. The DLH measurement results will be used as data in the analysis of the ability of vegetation to reduce air pollution by comparing $PM_{2.5}$ concentrations at the study sites.

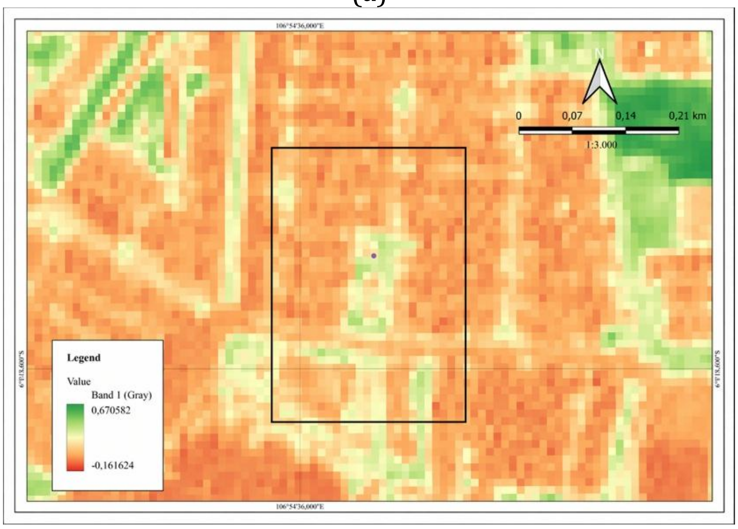
3. Results and Discussion

3.1 Characteristics of green open spaces and vegetation conditions

Tebet Eco Park represents a large-scale GOS with more optimal ecological capacity, while RPTRA Kelapa Nias III reflects a neighborhood-scale GOS with physical limitations but a strong social role. With this approach, the research does not focus on identifying which green open spaces are superior, but rather on how differences in the characteristics of green open spaces influence the ability of vegetation to reduce $PM_{2.5,}$ as well as the implications for green open space management strategies in various urban contexts. This approach is considered more reflective of cities' heterogeneous empirical conditions, thereby yielding findings that are more adaptive and relevant for the formulation of broad green space management policies.



(a)



(b)

Fig . 1. NDVI distribution at (a) Tebet Eco Park and (b)RPTRA Kelapa Nias III

Tebet Eco Park is locatedin Tebet Subdistrict, South Jakarta, covering approximately 7.3 ha, whereas RPTRA Kelapa Nias III is located in Kelapa Gading Subdistrict, North Jakarta, with an area of approximately 0.12 ha. Vegetation mapping using Normalized Difference Vegetation Index (NDVI) analysis yielded significant results (Figure 1). Figure 1 shows the differences in vegetation density between Tebet Eco Park and RPTRA Kelapa Nias III. Tebet Eco Park demonstrates higher NDVI values, indicating a denser and healthier vegetation cover compared with RPTRA Kelapa Nias III, which exhibits lower vegetation density and more limited ecological coverage.

3.2 Vegetation structure and composition

Based on the analysis results in Table 2, the tree-level vegetation structure at TEP shows fairly clear variations in species dominance, as reflected by the IVI values. The species with the highest IVI is Trembesi (*Samanea saman*) at 43.31%, followed by Flamboyant

(*Delonix regia*) at 40.85% and Mahogany (*Swietenia mahagony*) at 37.70%, indicating that these three species play the most dominant ecological roles in the local vegetation community. This dominance is primarily influenced by a combination of high relative density (RDe), relative frequency (RF), and relative dominance (RDo) values, particularly in Trembesi and Soga (*Peltophorum pterocarpum*), which exhibit relatively high RD values, reflecting a significant contribution of the basal area to the stand structure. Conversely, species such as Bungur Ungu (*Lagerstroemia speciosa*), Gadog, and Jati (*Tectona grandis*) have relatively low IVI values. Overall, this pattern indicates that the vegetation composition of Tebet Eco Park is dominated by tree species with large canopies that serve ornamental and shade-providing functions, which has implications for the character of the urban ecosystem.

Table 2. Results of the IVI calculation at the Tree Level at Tebet Eco Park

Local Name	Scientific Name	RDe (%)	RF (%)	RDo (%)	IVI (%)
Leda	*Eucalyptus deglupta*	14.29	10	8.49	32.78
Bodhi	*Ficus religiosa*	9.52	5	1.67	16.19
Trembesi	*Samanea saman*	12.70	15	15.61	43.31
Kecrutan	*Spathodea campanulata*	12.70	5	1.38	19.08
Mahoni	*Swietenia mahagoni*	12.70	10	15.00	37.70
Flamboyan	*Delonix regia*	11.11	15	14.74	40.85
Khaya	*Khaya senegalensis*	11.11	10	8.66	29.77
Bungur Ungu	*Lagerstroemia speciosa*	1.59	5	1.28	7.87
Jati	*Tectona grandis*	3.17	10	1.45	14.62
Ketapang	*Terminalia mantaly*	3.17	5	9.46	17.63
Soga	*Peltophorum pterocarpum*	4.76	5	18.61	28.37
Gadog	*Bischofia javanica*	3.17	5	3.65	11.82
Total		100	100	100	300

The Shannon–Wiener diversity index (H') of 2.32 indicates a moderate level of species diversity at Tebet Eco Park. This value suggests that the vegetation community has a relatively balanced distribution of individuals among species, with no single species dominating the community. Moderate species diversity contributes to a more heterogeneous vegetation structure, which may support multiple ecological functions in urban green spaces. These findings indicate that Tebet Eco Park maintains a relatively diverse tree community compared with many urban parks.

Based on the results of the IVI calculations at the tree level in the Kelapa Nias III RPTRA, as shown in Table 3, the vegetation community structure exhibits a strong dominance pattern by several species. Trembesi (*Samanea saman*) species, with the highest IVI of 86.58%. This high value reflects a very significant contribution from relative density, relative frequency, and especially relative dominance (RDo), which reached 48.39%, indicating the major role of Trembesi in shaping stand structure through basal area and control of growing space both vertically and horizontally. Other species, such as Kecrutan (*Spathodea campanulata*) and Palem (*Roystonea regia*), also exhibit relatively high IVI values, at 62.77% and 59.39%, respectively, reflecting an even distribution of individuals (RF = 20%) and an important structural role in shaping the canopy composition and vegetation landscape of the area. Glodokan (*Polyalthia longifolia*) has the lowest IVI value (42.47%), indicating a limited contribution to stand dominance, although it still exhibits an even frequency distribution.

This pattern suggests that the vegetation community at RPTRA Kelapa Nias III tends to be homogeneous. Several factors that can influence the level of vegetation diversity in urban green spaces are limited land availability, decision-making involving various human actors, and the selection of species that are tolerant of urban environmental conditions (Hilbert et al., 2023; Ye et al., 2025). The relatively limited area of the RPTRA, approximately 0.2 ha may have contributed to the observed species dominance pattern and IVI values. Competition among individuals for light, growing space, and edaphic resources tends to be more intense in confined spaces, so species with superior morphological characteristics—

such as the Trembesi, which has a broad canopy and a large-diameter trunk—are better able to dominate the stand structure. This condition is reflected in the high RDe and IVI values of Trembesi compared with those of other species. Furthermore, the limited area also results in low habitat heterogeneity, which restricts growth opportunities for species with specific ecological requirements and ultimately leads to a more homogeneous community composition. From the perspective of urban green open space management, these findings indicate that planting strategies and species selection play a crucial role in shaping vegetation structure and ecosystem functions in small-scale areas (Lartey et al., 2025). Therefore, a more adaptive approach to species enrichment and planting density is needed to maintain a balance between structural dominance, biodiversity, and ecological function long-term sustainability.

Table 3. Results of the IVI Calculation at the Tree Level at RPTRA Kelapa Nias III

Local Name	Scientific Name	RDe (%)	RF (%)	RDo (%)	IVI (%)
Palem	*Roystonea regia*	9.09	z	30.40	59.49
Kecrutan	*Spathodea campanulata*	36.36	20	6.41	62.77
Seri	*Muntingia calabura*	18.18	20	10.61	48.79
Trembesi	*Samanea saman*	18.18	20	48.39T	86.58
Glodokan	*Polyalthia longifolia*	18.18	20	4.29	42.47
Total		100	100	100	300

The Shannon–Wiener diversity index (H') is 1.52, indicating that the level of species diversity in the vegetation community falls into the moderate category. Ecologically, this value indicates that the community is not extremely dominated by a single species but has not yet reached a high and balanced level of diversity. This condition reflects a combination of several relatively dominant species with other species of lower abundance such that the distribution of individuals among species is not yet fully even. In urban ecosystems such as RPTRA, an H' value in this range is often associated with the influence of human intervention through directed planting patterns and spatial constraints, which tend to limit natural colonization processes and the formation of more complex community structures. Therefore, this value implies that species enrichment and improving the evenness of stand structure are necessary to promote higher diversity, strengthen ecological functions, and enhance the long-term sustainability of urban green open spaces without compromising the social functions and comfort of public spaces.

3.3 Association between vegetation characteristics and PM2.5 concentrations

The annual mean ambient $PM_{2.5}$ concentration associated with Tebet Eco Park was 28 $\mu g/m^3$, whereas the annual mean concentration associated with RPTRA Kelapa Nias III was 31.9 $\mu g/m^3$. When compared to the vegetation conditions at the existing sites, Tebet Eco Park has lower $PM_{2.5}$ levels than RPTRA. This aligns with Wu et al. (2021), who demonstrates that plant biodiversity plays a role in enhancing the effectiveness of air pollution mitigation. Several plant species found at this TEP site have been studied for their ability to reduce $PM_{2.5}$ levels. Yuniati et al. (2024) measured PM adsorbed on leaf surfaces and found that Swietenia macrophylla and Terminalia mantaly are capable of capturing PM from the air (using a gravimetric method to count particles adhering to the leaves). Additionally, Devi et al. (2023) compared 20 tree species and reported that Tectona grandis and several Ficus species exhibit high PM capture capacity due to their rough leaf surfaces. Singh et al. (2025) also stated that the species *Swietenia macrophylla*, *Khaya senegalensis*, *Ficus religiosa*, and *Samanea saman* have high Air Pollution Tolerance Index (APTI) and good dust retention, indicating that these species are tolerant of pollution and capable of trapping airborne particles on their leaves.

In addition to the plants found at the TEP site, the plants at RPTRA Kelapa Nias III were also examined beforehand regarding the availability of articles or studies that have tested the species found at the site for their ability to reduce $PM_{2.5}$. A study conducted by Yuniati et al. (2024)compared the PM adsorbed on leaf surfaces of several tree species using the gravimetric method. The findings of this study indicated that the species Polyalthia longifolia exhibited the highest level of adsorbed particulate matter among the tested species, demonstrating its capacity to effectively capture PM on leaf surfaces in an urban environment. Additionally, Syahadat et al. (2020) stated that Spathodea campanulata is one of the species that actively absorbs particulate pollutants (dust/PM) due to leaf structures that support dust retention. *Spathodea campanulata* possesses good particle absorption capacity, ranking only slightly below *Swietenia mahagoni* in terms of particle filtration through leaves.

No scientific articles or studies have yet been published on the capabilities of other species. However, this does not mean that these plants are ineffective at absorbing pollutants. A research conducted by Chen et al. (2024) shows that trees with rough leaf surfaces, broad canopy profiles, and high stomatal density tend to have the potential to capture fine particles such as $PM_{2.5}$.although specific findings may vary between locations and species, depending also on the meteorological conditions of the environment or study site (Kwak et al., 2019). Based on the results of vegetation analysis at Tebet Eco Park and RPTRA Kelapa Nias III, Shannon diversity index (H') values were obtained, indicating differences in the level of vegetation diversity between the two study sites. No published studies were found evaluating the PM2.5 capture capacity of several other species identified in this study. However, previous research suggests that trees with rough leaf surfaces, broad canopies, and high stomatal density generally have greater potential to capture fine particulate matter, although this varies among species and environmental conditions (Kwak et al., 2019). The higher Shannon diversity index (H') observed at Tebet Eco Park indicates greater species diversity, which may contribute to a wider range of vegetation characteristics associated with particulate capture. Nevertheless, these mechanisms were not directly measured in the present study.

Tebet Eco Park, which has a higher H' value, shows lower recorded $PM_{2.5}$ concentrations alongside higher vegetation diversity and canopy complexity compared with RPTRA Kelapa Nias III. This pattern may be partly explained by the more complex vegetation structure at Tebet Eco Park, which allows for the formation of a multi-layer canopy. This structure increases air turbulence and slows particle movement, thereby increasing the likelihood of particulate deposition on leaf surfaces. Conversely, the simpler vegetation structure at RPTRA Kelapa Nias III allows for relatively freer airflow, resulting in shorter particle residence times and lower $PM_{2.5}$ capture efficiency. These findings are consistent with the are consistent Shen et al. (2022), who stated that the complexity of vegetation structure significantly influences particulate capture efficiency in urban environments.

In addition, differences in H' values between the two locations also influence leaf morphological variation, which plays a role in the adsorption and deposition mechanisms of $PM_{2.5}$. Tebet Eco Park exhibits a wider range of leaf characteristics—such as rough, hairy, or waxy leaf surfaces—which collectively enhance particulate capture capacity. Conversely, the more homogeneous vegetation at RPTRA Kelapa Nias III exhibits limited leaf morphological variation, resulting in suboptimal $PM_{2.5}$ capture capacity. Gaglio et al. (2022) and Chen et al. (2017) indicated that differences in leaf characteristics among species significantly determine the effectiveness of particulate accumulation, with leaves possessing complex microstructures exhibiting higher capture capacity.

Thus, a comparison between Tebet Eco Park and RPTRA Kelapa Nias III shows that locations with higher H' values in this study tended to show lower PM2.5 concentrations, although this pattern may also be influenced by surrounding urban conditions. This is influenced not only by the amount of vegetation but also by the diversity of species that form a complex canopy structure, increase leaf morphological variation, and expand the surface area for particulate absorption. Variation among species is another key factor in determining the effectiveness of vegetation in removing air pollutants (Lindén et al., 2023).

These findings suggest that vegetation diversity should be considered an important component of urban green space management for improving air quality, alongside increasing vegetation cover and other urban air pollution control strategies. . This finding also supports previous studies indicating that urban green areas with higher vegetation diversity and canopy coverage tend to achieve greater PM removal efficiency due to increased surface area for particle deposition and interception (Brito & Rizzo, 2022).

The role of vegetation as a biological filter is primarily driven by leaf-level processes, where PM is captured through adsorption and deposition on leaf surfaces. Leaves act as the main interface between vegetation and airborne particles, enabling urban vegetation to function as an active air purification system rather than merely a passive landscape element (Mandal et al., 2023) . In this context, the presence of multiple species in Tebet Eco Park enhances the diversity of leaf morphology and surface characteristics, which collectively improve the overall capacity for $PM_{2.5}$ capture. Conversely, the relatively homogeneous vegetation structure in RPTRA Kelapa Nias III limits the variation in particulate capture mechanisms, resulting in lower mitigation effectiveness.

In addition to biodiversity, canopy structure plays a crucial role in determining the capacity of vegetation to reduce $PM_{2.5}$ concentrations. Complex canopy structures—characterized by greater canopy area, density, and vertical layering—can enhance particulate interception and influence local airflow dynamics, thereby increasing deposition rates. Previous studies have shown that canopy attributes such as leaf area index (LAI), canopy volume, and tree height significantly affect $PM_{2.5}$ removal processes by altering turbulence and air residence time (Huang et al., 2025). Although these canopy attributes were not quantified in the present study, Tebet Eco Parkis dominated by large-canopy trees such as *Samanea saman* and *Swietenia mahagoni*, which may partly explain its lower recorded PM2.5 concentrations compared with the simpler vegetation structure at RPTRA Kelapa Nias III.

Furthermore, the spatial scale of green spaces contributes to differences in $PM_{2.5}$ mitigation effectiveness. Larger green areas such as Tebet Eco Park, allow longer interactions between air masses and vegetation, increasing the likelihood of particle deposition. This is consistent with comparative studies showing that areas with higher vegetation cover can reduce $PM_{2.5}$ concentrations by up to 30% compared with areas with limited vegetation (Junior et al., 2022). In contrast, smaller green spaces like RPTRA Kelapa Nias III, although still beneficial, have limited capacity to influence air quality due to shorter air residence time and reduced vegetation density.

From a public health perspective, the observed association is important because lower ambient $PM_{2.5}$ concentrations in green open spaces may indicate potential benefits for reducing exposure among park users, pedestrians, children, older adults, and other vulnerable urban populations. However, this study cannot quantify individual exposure reduction because $PM_{2.5}$ data were obtained from secondary environmental monitoring rather than direct pedestrian-level measurements within each green space. Therefore, this study's public health implication lies in identifying vegetation diversity and canopy complexity as potential environmental health-supporting factors that should be considered in urban green space planning.

These findings suggest that urban green space management should focus not only on increasing green area but also on improving vegetation quality, species diversity, canopy layering, and plant placement in areas with high human activity. Future studies should include direct PM2.5 measurements within green spaces, repeated seasonal observations, traffic assessments, and meteorological analyses to better distinguish the contribution of vegetation from other urban environmental factors and strengthen the evidence for public health applications.This highlights the importance of strategic vegetation planning in urban environments, where increasing biodiversity and optimizing structural complexity can significantly enhance the role of green spaces as nature-based solutions for air pollution mitigation.

4. Conclusions

This study found that vegetation diversity and structural complexity potentially support the effectiveness of UGOS in reducing $PM_{2.5}$ concentrations. The comparative analysis shows that Tebet Eco Park, with higher species diversity (H' = 2.32) and a complex canopy structure, recorded lower $PM_{2.5}$ concentrations (28 μg/m^3) compared to RPTRA Kelapa Nias III, which has relatively homogeneous vegetation (H' = 1.52; 31.9 μg/m^3).

These findings suggest that vegetation diversity may contribute to improved air quality, while previous studies indicate that canopy structure and leaf characteristics could partly explain this association. However, these mechanisms were not directly examined in the present study. . In contrast, limited spatial extent and structurally simplified vegetation reduce aerodynamic resistance and particle residence time, thereby constraining $PM_{2.5}$ removal efficiency.

The findings are limited to two sites in Jakarta with different spatial and environmental characteristics. Because the study used secondary ambient $PM_{2.5}$ data and did not directly measure pedestrian-level exposure, traffic intensity, meteorological conditions, or local emission sources, the results should be interpreted as an observed association rather than a direct causal relationship. Therefore, caution is needed when applying these findings to other urban green spaces with different environmental conditions.

The findings suggest that vegetation diversity should be considered in urban green space planning to enhance potential air quality benefits. Together with evidence from previous studies, increasing species diversity and maintaining structurally diverse vegetation may improve the ecological performance of urban green spaces. Future planning should combine vegetation assessment with site-level $PM_{2.5}$ monitoring, traffic data, meteorological measurements, and pedestrian exposure assessments to better evaluate the contribution of vegetation to urban air quality and public health.

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Author Contribution
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In preparing this work, Grammarly was used to support improvements in grammar. The authors subsequently reviewed and refined the text and assume full responsibility for the content.

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